6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.9 LIGHT FIXTURES

6.4.9.3 PENDANT LIGHT FIXTURES

This section covers pendant light fixtures, chandeliers, ceiling fans, and other similar suspended items.

TYPICAL CAUSES OF DAMAGE

- Suspended items can swing and impact building elements or adjacent equipment, resulting in damage to the fixture or damage to the surrounding items. Lenses, bulbs, or decorations may come loose and fall and endanger occupants.
- If the item is not sufficiently well supported, or if the item is connected only to ceiling framing which is damaged in an earthquake, the entire fixture may become dislodged and fall. Where a string of fixtures are attached end to end, the failure of one fixture can overload the supports for the adjacent fixtures leading to progressive collapse.

Damage Examples

Figure 6.4.9.3-1 Failure of a strip of pendant light fixtures at Dawson Elementary School library as a result of the 1983 magnitude-6.4 Coalinga Earthquake. Note that in this case the support stems failed at the ceiling connection and the stem came down with the lights (Gary McGavin, NGDC, 2009).

Figure 6.4.9.3-2 Failure of pendant light fixtures at Northridge Junior High School as a result of the 1994 Northridge Earthquake. In this example, the support stem failed at the fixture connection and the stem is still attached at the ceiling (Photo courtesy of Gary L. McGavin).

Figure 6.4.9.3-3 Failure of pendant light fixture in the 2010 magnitude-7 Haiti Earthquake; stem of fixture broke and conduit pulled loose (Photos courtesy of Eduardo Fierro, BFP Engineers).

SEISMIC MITIGATION CONSIDERATIONS

- All light fixtures should have positive attachments to the structure to prevent falling hazards. Per ASTM E580, *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions* (ASTM, 2010), pendant fixtures in suspended ceilings must be supported directly from the structure above by no less than #9 gauge wire or an approved alternate support. The ceiling suspension system shall not provide any direct support and rigid conduit is not permitted for the attachment of fixtures.
- For California schools, DSA IR 25-5, *Metal Suspension System for Lay-in Panel Ceilings* (California Department of General Services, 2009c), requires the following: "Support pendant mounted light fixtures directly from the structure above with hanger wires or cables passing through each pendant hanger and capable of supporting two (2) times the weight of the fixture. A bracing assembly, (see Section 6.3.4.1), is required where the pendant hanger penetrates the ceiling. Special details are required to attach the pendant hanger to the bracing assembly to transmit horizontal force. If the pendant mounted light fixture is directly and independently braced below the ceiling, i.e. aircraft cables to walls, then brace assembly is not required above the ceiling." See DSA IR 16-9*, Pendant Mounted Light Fixtures* (California Department of General Services, 2009a), for additional requirements for pendant mounted fixtures.
- For older installations, provide a safety chain or cable for the fixture and provide restraints for lenses and bulbs that can readily fall from the fixture.
- If the fixture can impact other items and cause failure of an essential component, or if impact can create a falling hazard, then seismic restraints that limit the range of motion of the fixture should be installed.

Mitigation Details

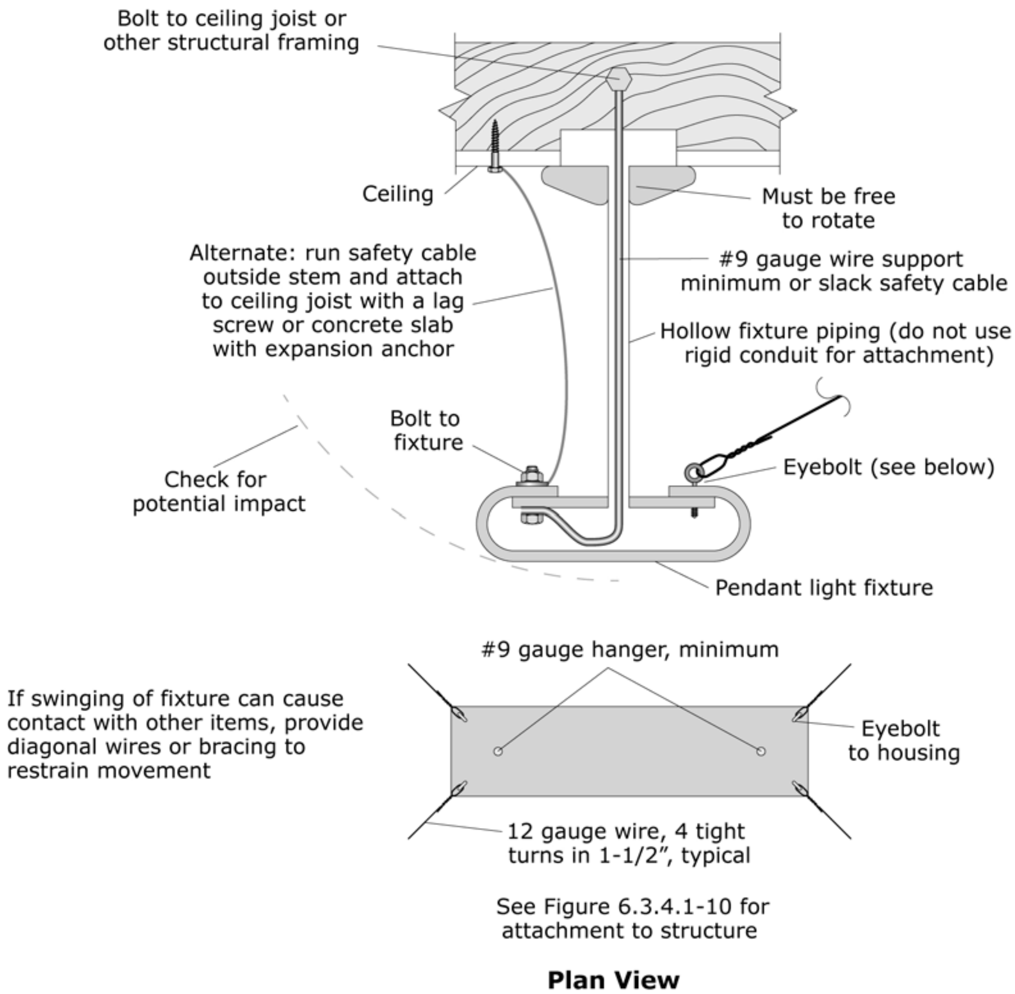


Figure 6.4.9.3-4 Pendant light fixture (NE).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.9 LIGHT FIXTURES

6.4.9.4 HEAVY LIGHT FIXTURES

This category covers heavy or special purpose overhead light fixtures that require engineered support details. This includes fixtures such as hospital operating room lights which also have movable arms. Damage to overhead lighting has occurred frequently in past earthquakes; special purpose lighting has additional issues in that the fixture may have internal joints and movable parts which may not have not been designed for seismic loading.

TYPICAL CAUSES OF DAMAGE

- Heavy or special purpose lighting can fail at the attachment to the structure above if not adequately designed and the fixture could fall and injure occupants. Overhead braces may buckle and the fixture will be misaligned or fail to function as intended.
- Fixtures with multiple parts or movable arms may fail at the connections or arm joints; bulbs or lenses may fall.
- Bracing for the light fixture and surrounding ceiling should be coordinated to allow for relative movement. If the ceiling surround has not been designed with appropriate clearance around the fixture, the ceiling may be damaged at the interface with the light.

Damage Examples

Figure 6.4.9.4-1 Operating room lights undamaged although hospital evacuated due to collapse of adjacent wing in the 2010 magnitude-7 Haiti Earthquake. Fixture anchored to underside of concrete slab (Photo courtesy of Ayhan Irfanoglu, Purdue University).

SEISMIC MITIGATION CONSIDERATIONS

- Per ASTM E580, *Standard Practice for Installation of Ceiling Suspension Systems for Acoustical Tile and Lay-in Panels in Areas Subject to Earthquake Ground Motions* (ASTM, 2010), where the weight of a fixture in a suspended acoustic ceiling is greater than 56 pounds, the fixture must be supported directly from the structure above by approved hangers. Where the fixture is over 56 pounds but light enough so that the lateral restraint for the fixture can be provided by the lateral bracing for the ceiling grid, these fixtures must also be positively attached to the ceiling grid with a minimum of two attachment devices capable of resisting 100% of the fixture weight in any direction. This condition is covered in Sections 6.4.9.1 and 6.4.9.2.
- Lights covered here are those heavier than can be safely supported by the suspended ceiling grid and require independent engineered supports for both vertical and lateral

loads. In addition, special purpose lighting with movable parts may require more fixity than provided by the ceiling grid and require independent support and bracing to maintain position and satisfy operational tolerances.

- Note that fixed lighting provides an obstruction for a suspended ceiling system. For suspended acoustic ceilings in Seismic Design Category D, E & F, ASTM E580 requires that the ceiling surrounding such a fixture must be detailed as if it were a perimeter closure that must allow the required clearances by use of suitable closure details; this typically would require a minimum ¾" clearance around the fixture.
- When purchasing heavy light fixtures that have multiple part or movable arms, check with the manufacturer for seismically qualified fixtures. Certified fixtures are required for hospitals or essential facilities that must remain functional following an earthquake per Section 13.2.2.1 of ASCE 7-10, *Minimum Design Loads for Buildings and Other Structures* (ASCE, 2010).

Mitigation Examples

Figure 6.4.9.4-2 Engineered support and bracing are required for heavy operating room lights. The arms, joints, lenses and bulbs must be capable of resisting seismic forces. Hospital fixtures require certification. Photo also shows surface mounted fluorescent fixtures in a suspended gypsum board ceiling; each of these requires independent safety wires to the structure above; see Section 6.4.9.2 (Photo courtesy of Maryann Phipps, Estructure).

Figure 6.4.9.4-3 Engineered support and bracing for operating room lights located in California hospital. Steel plate has predrilled holes to receive fixture attachments (Photo courtesy of Maryann Phipps, Estructure).

Mitigation Details

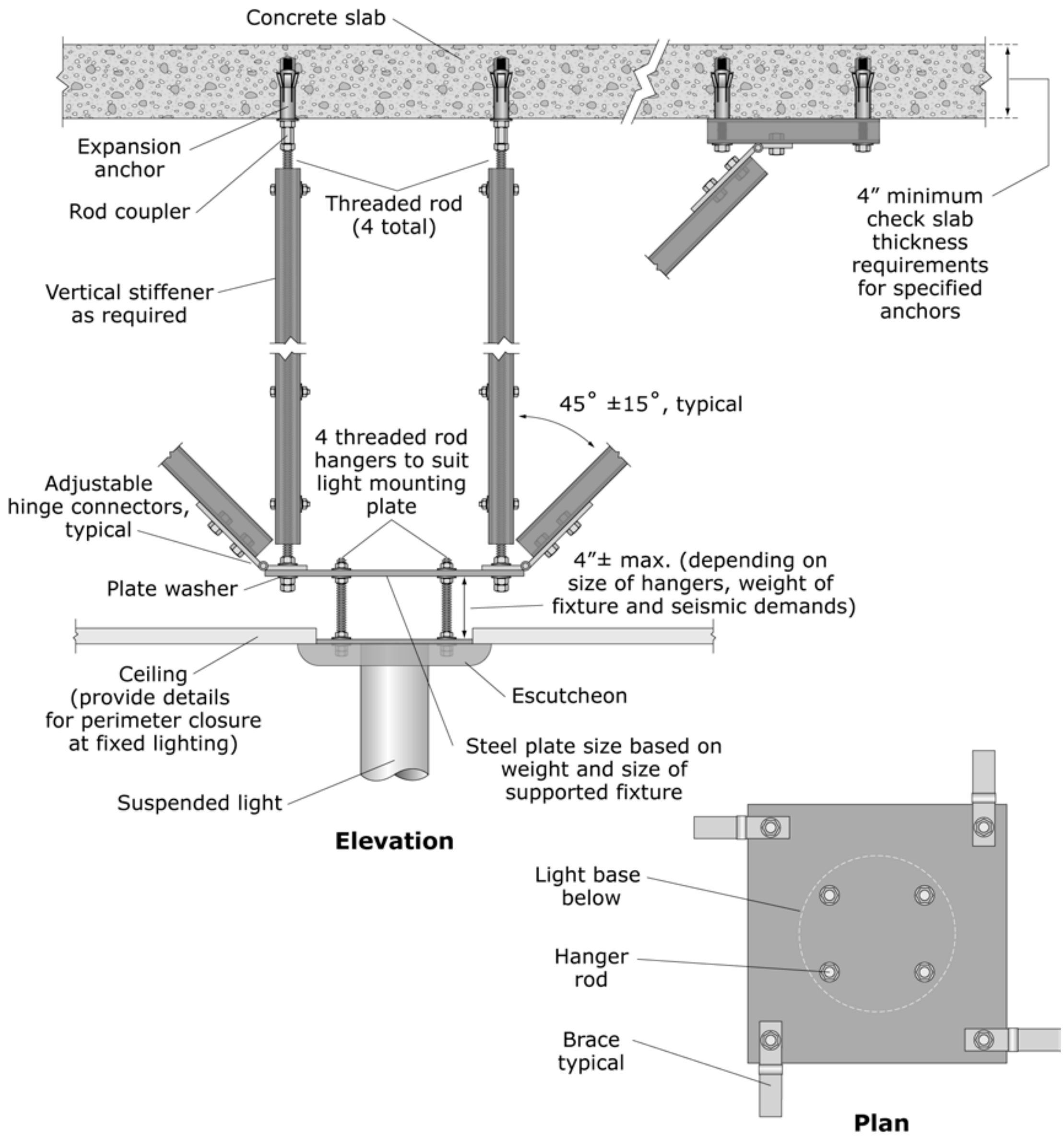


Figure 6.4.9.4-4 Details for supporting heavy light fixture directly from structure (ER).

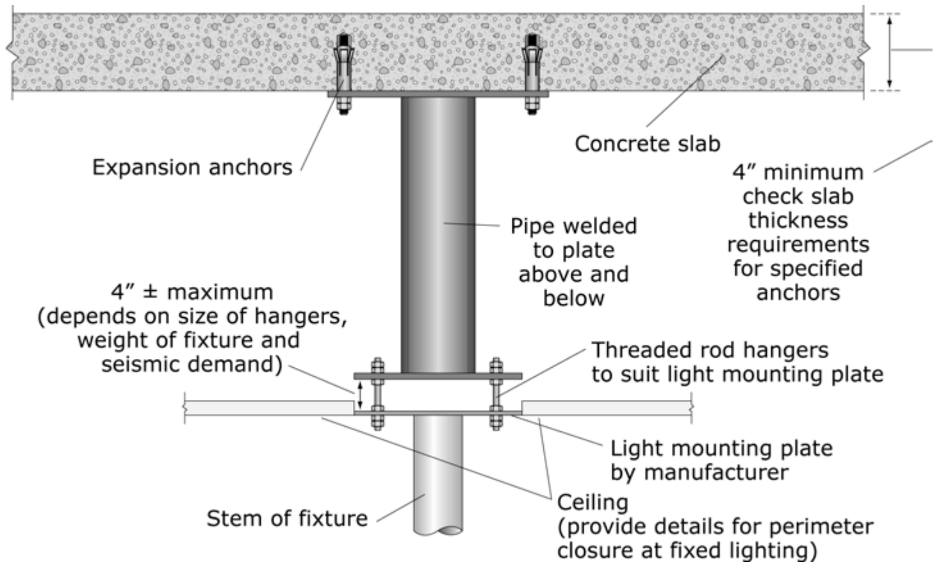


Figure 6.4.9.4-5 Details for supporting heavy light fixture directly from structure (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.10 ELEVATORS AND ESCALATORS

6.4.10.1 HYDRAULIC ELEVATORS

Hydraulic elevators consist of relatively simple mechanical systems but failure of any of the component parts could disable the functionality of the entire system. These elevators are typically limited in height since they require a cylinder beneath the elevator equal to the height of the elevator cab's vertical travel.

TYPICAL CAUSES OF DAMAGE

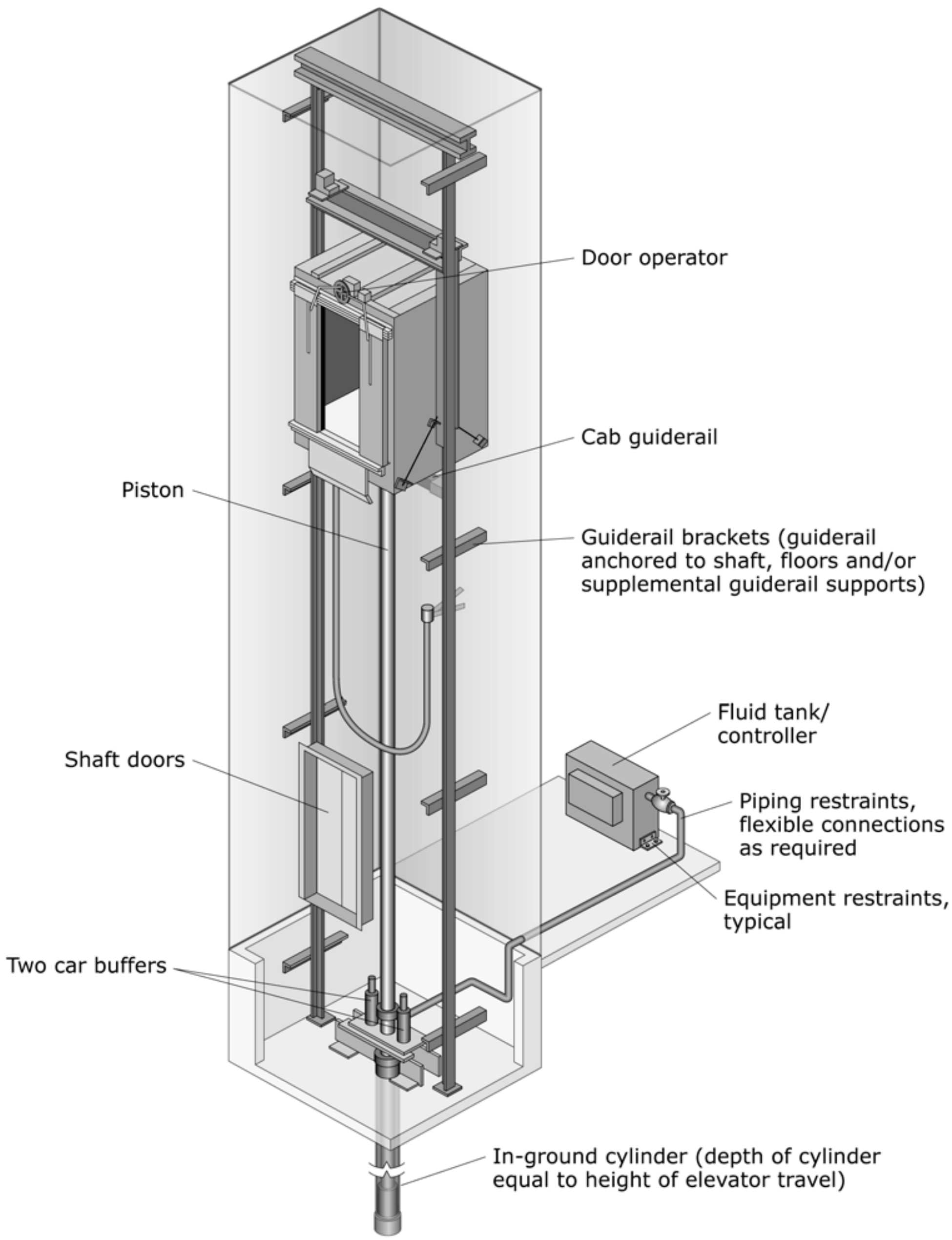
- The primary components of the hydraulic elevator system are the elevator cab, cab guides, doors and door mechanism, piston, cylinder, fluid reservoir, hydraulic fluid, rotary pump, valve, solenoid switch, and electrical control panel. The system may be tied to a seismic switch or a smoke detector which would facilitate safe shutdown in the event of an earthquake or fire. Any of these components could be damaged if not properly restrained. Other possible failures are: misalignment of cab guides or cylinder, deformed door frames impeding the operation of doors, failure of door rails, leakage of hydraulic fluid, damaged pump.
- According to survey responses collected by the Division of Occupational Safety and Health Elevator, Tramway, and Ride unit, following the 1994 Northridge Earthquake 897 hydraulic elevators suffered damage such as leaks in underground feed lines, separated pipes, and failed gaskets and fittings. In addition, numerous guide rails were bent and several cars came out of rails. Tie downs on several oil tanks failed and hold-down bolts sheared and pulled out.
- In addition to property damage, passengers may become trapped in the cab following an earthquake and may need to await extraction by qualified elevator technicians.

SEISMIC MITIGATION CONSIDERATIONS

- All components of the hydraulic system need to be restrained, anchored or detailed to accommodate movement to prevent damage in an earthquake. The system must be designed to accommodate the anticipated inter-story drift over the height of the elevator travel and the depth of the cylinder below. Components such as cab guides, door frames, and cylinder supports must all be detailed to accommodate lateral deformations. All mechanical and electrical equipment, sensors, piping, tanks, valves, and guides need to be properly anchored or restrained.

- All elevators should be inspected by qualified elevator technicians following an earthquake. Elevators should have a seismic switch or safety features that allow for safe shutdown in an earthquake.
- Elevator safety is governed by the prescriptive requirements in ASME A17.1/CSA B44, *Safety Code for Elevators and Escalators* (ASME, 2007a) a document that is continually evolving to reflect new elevator technologies. In addition, ASME A17.7/B44.7, *Performance Based Code for Elevator Safety* (ASME, 2007b), is the next step in the evolution of elevator safety codes in the United States and Canada. Local or state jurisdictions may have other elevator requirements.
- The internet provides information regarding hydraulic elevators. A few websites are linked below:
  - The website http:science.howstuffworks.com/elevator1.htm describes the workings of hydraulic elevators and provides links to other resources
  - Jobsite safety in the elevator industry is discussed on http://safety.elevator-world.com/disaster.htm
  - The websites of the Elevator and Escalator Safety Foundation, http://eesf.org/, and major elevator suppliers such as The Otis Elevator Company and Schindler Elevators provide additional resources.
  - The National Elevator Industry, Inc. has other resources including a discussion of the performance based code for elevator safety (http://www.pbc-elevators.com/).

Mitigation Details



Notes: Provide lateral restraints for guiderails to resist design forces and accommodate anticipated interstory drift.
Elevators should be installed, maintained, inspected and repaired by qualified elevator technicians.
Inappropriate seismic restraints may compromise the safe operation of these systems.

Figure 6.4.10.1-1 Schematic view of hydraulic elevator (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.10 ELEVATORS AND ESCALATORS

6.4.10.2 TRACTION ELEVATORS

Traction elevators have made high rise construction possible. These systems are continually evolving to achieve faster speeds, smoother and quieter operations. Currently there are geared traction elevators, gearless traction elevators, and "machine-roomless" elevators that use flat belts instead of steel cable. Traction elevators are complex mechanical systems that have many moving parts and electronic components and failure of any of the components could disable the functionality of the entire system. Maintaining limited functionality of some elevators following an earthquake is critical for continued operations of essential facilities or the evacuation of hospital patients.

TYPICAL CAUSES OF DAMAGE

- The primary components of the traction elevator system are the elevator cab, counterweight, cab guide rails, counterweight guide rails, guide rail support brackets, electric motor, electrical control panel, ropes, sheaves, safety braking mechanisms, door mechanisms, and a shock absorber at the bottom of the shaft. The system may be tied to a seismic switch or a smoke detector which would facilitate safe shutdown in the event of an earthquake or fire. Any of these components could be damaged if not properly restrained. Other possible failures are: misalignment of cab guides, deformed door frames impeding the operation of the doors, failure of door rails, misalignment of the cab or counterweight, and damage to the mechanical or electrical equipment. Failures of counterweights can result in falling hazards if the subweights can come loose of the counterweight assembly.
- According to survey responses collected by the Division of Occupational Safety and Health Elevator, Tramway, and Ride unit, following the 1994 Northridge earthquake, the following issues were observed:
  - Water damage-sprinkler pipes pulled apart flooding machine rooms and pits causing water on top of cars, damage to door operators and door detectors, and soaking car processors and car station. Several oil buffers had to be rebuilt.

- Falling debris in hoistways, falling plaster, loose concrete blocks, broken glass resulted in damaged door interlocks and misalignment of hatch switches and bent fascias.
- Building settlements bent elevator guide rails; structural damage, loose and bent divider beams shifted guide rails and bending support brackets.
- 3,528 cabled elevators were removed from service by a seismic protective device. 710 devices did not operate as intended. Some devices were located in the elevator pits which were flooded.
- 968 electric cabled elevators sustained earthquake damage.
- 2 minor injuries were reported, one of which was sustained by a fireman trying to open hoistway doors.
- 39 elevators required rescue.
- 57 instances were reported where "unauthorized persons" reset earthquake devices. Fortunately, only 5 elevators sustained additional damages.
- 688 counterweights came out of guide rails. 8-1b rails were inadequate even with additional intermediate guide rail bracket retrofit. Several counterweight frames were twisted and bent with a few dislodged subweights. Some counterweight roller guide shoe mountings disintegrated.

- Following the 2010 Chile Earthquake, it was reported that 50%-80% of hospital elevators were damaged. In a number of locations, patients had to be carried down many flights of stairs, often cluttered with fallen debris, in order to evacuate them to safety. The most common damage was due to unrestrained movement of the counterweights, resulting in damage to the guide rails. Movement of unrestrained mechanical equipment was another problem. One security camera at a military hospital in Santiago, Chile captured a sequence through the open door of an empty elevator cab where the counterweights derailed and then the subweights came crashing down on top of the cab. (Source: Bill Holmes, March 2010).
- In addition to property damage, passengers may become trapped in the cab following an earthquake and may need to await extraction by qualified elevator technicians.

Damage Examples

Figure 6.4.10.2-1 Damage to traction elevator in Chillán in the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Gilberto Mosqueda, SUNY Buffalo). The unanchored sheaves and motor above the 6th floor slid nearly off the housekeeping pad. The counterweight guide rails are bent due to impact with the counterweights. The guide rail support brackets have horizontal slots, but the bolt went through a welded tab (photo at lower right) and pulled out of the wall.

Figure 6.4.10.2-2 Derailed car roller assembly of the guide rail at the Santiago airport in the 2010 Chile Earthquake (Photo courtesy of Gilberto Mosqueda, SUNY Buffalo). The three rollers are supposed to travel along three sides of the stem of the T-shaped steel guide rail.

Figure 6.4.10.2-3 Glazing failures caused additional hazards at Santiago airport elevator in the 2010 Chile Earthquake (Photo courtesy of Antonio Iruretagoyena, Rubén Borsochek & Associates).

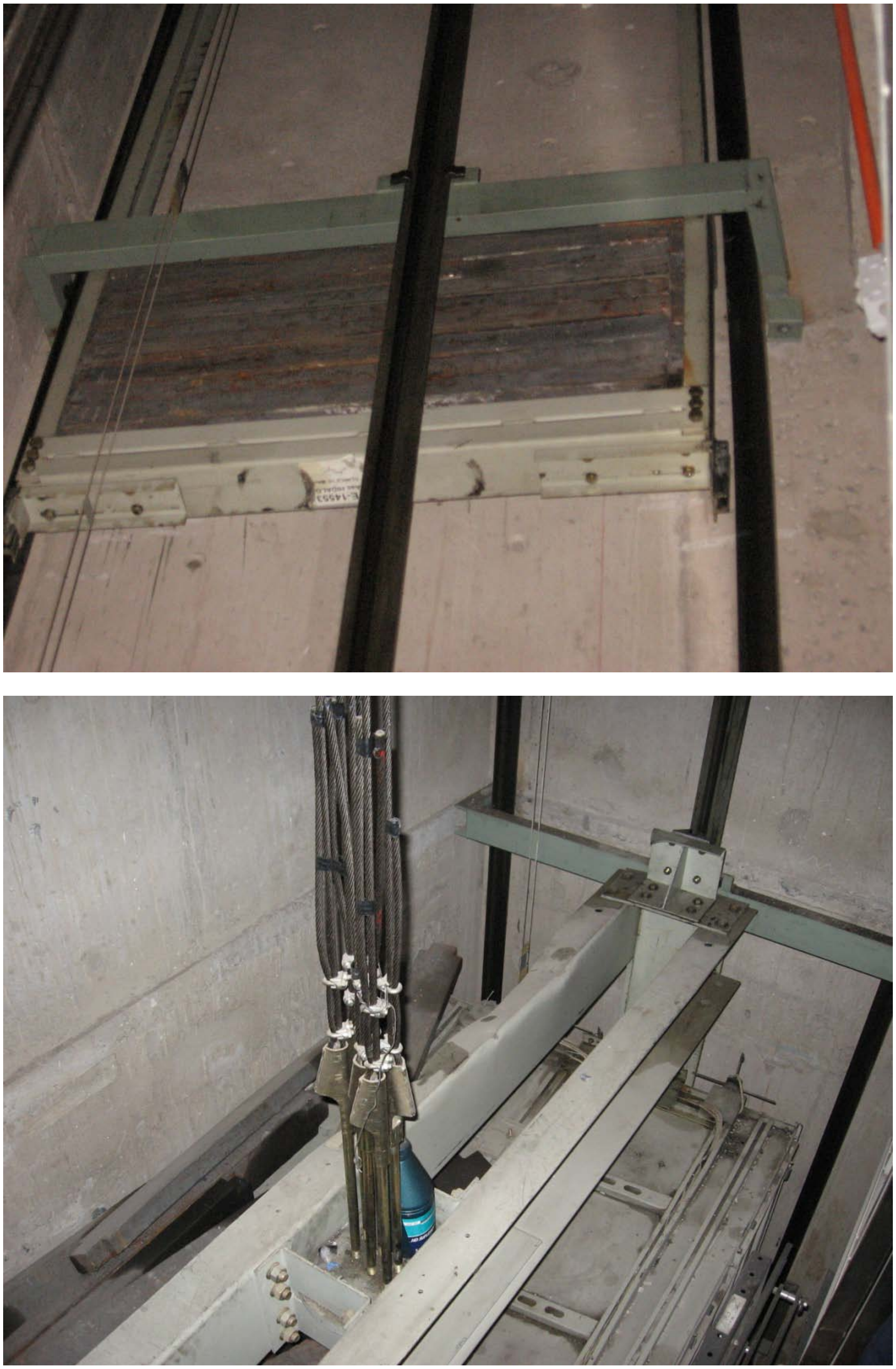


Figure 6.4.10.2-4 Unrestrained movement of the counterweights damaged the counterweight assembly and bent the counterweight guide rails; over half the subweights dropped onto the top of the cab and damaged the cab framing in the 2010 Chile Earthquake (Photo courtesy of Rodrigo Retamales, Rubén Borsochek & Associates).

Figure 6.4.10.2-5 Anchor bolt failure of the elevator generator set due to inadequate edge distance for the bolts at the Los Angeles Regional Public Hospital in the 2010 Chile Earthquake (Photo courtesy of Bill Holmes, Rutherford & Chekene).

SEISMIC MITIGATION CONSIDERATIONS

- All of the components of the traction system need to be restrained, anchored, or detailed to resist lateral forces in all directions and accommodate seismic movement. The system must be designed to accommodate the anticipated inter-story drift over the height of the elevator travel. Guide rails and door frames must all be detailed to accommodate lateral deformations. All of the mechanical and electrical equipment, sensors, and guides need to be properly anchored or restrained.
- All elevators should be inspected by qualified elevator technicians following an earthquake. Elevators should have a seismic switch or safety features that allow for safe shutdown in an earthquake.
- Elevator safety is governed by the prescriptive requirements in ASME A17.1/CSA B44 *Safety Code for Elevators and Escalators* (2007a), a document that is continually evolving

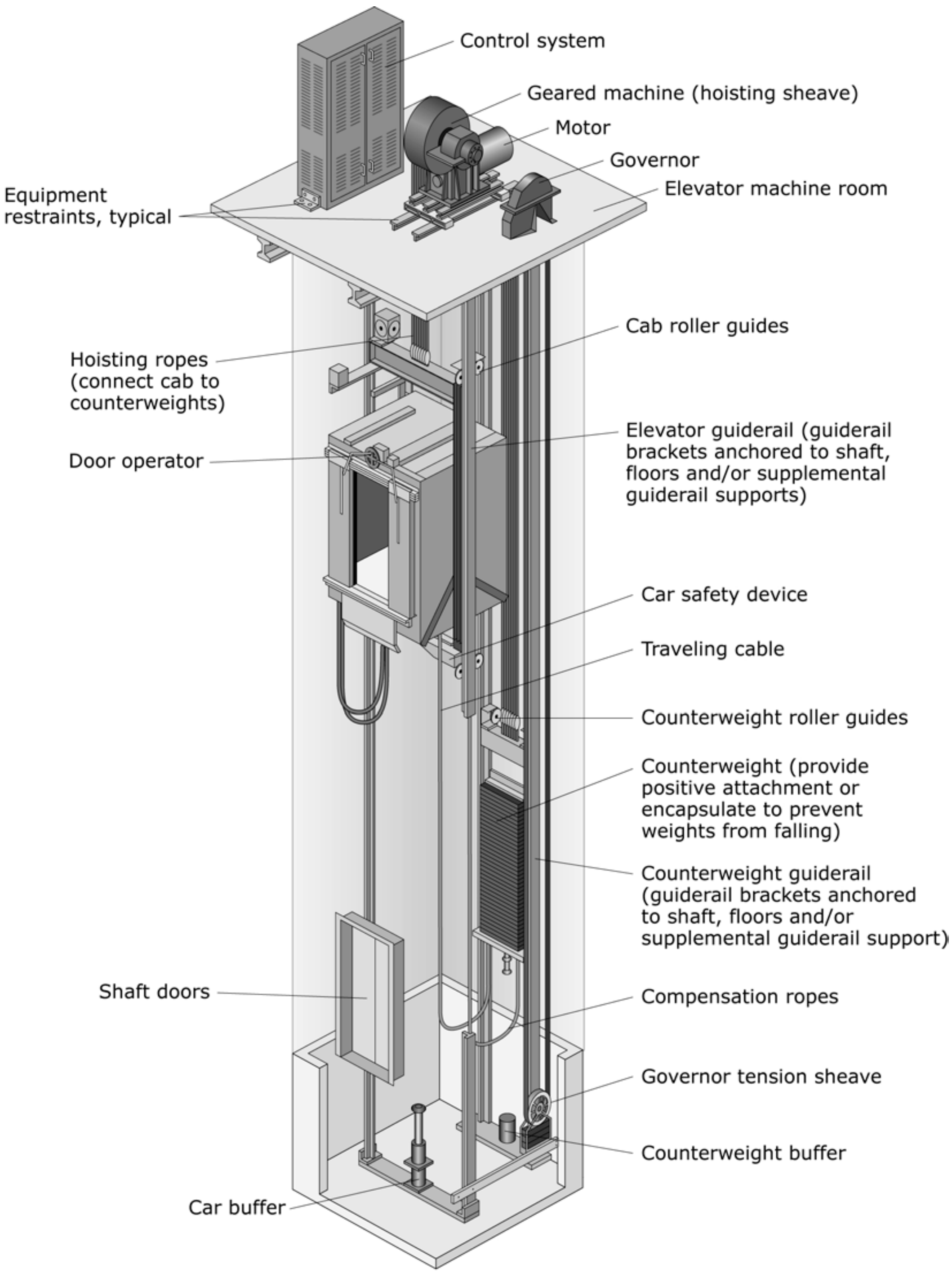
reflect new elevator technologies. In addition, ASME A17.7/CSA B44.7, *Performance Based Code for Elevator Safety* (ASME, 2007b), is the next step in the evolution of elevator safety codes in the United States and Canada. Local or state jurisdictions may have other elevator requirements.

- As an example of state jurisdictions, the California Office of Statewide Health Planning and Development (OSHPD) provides special requirements for elevators in California hospitals, such as Title 24, Section 3007. These include requirements for a seismic switch connected to the essential electrical system, a visible or audible alarm, the ability to function at a "go slow" speed of not more than 150 feet per minute until the elevator can be inspected, and an additional sensor that will disable the elevator if the governor tail sheave is dislodged. For these systems, the seismic anchorage, guards and switches all need to be inspected annually.
- The internet provides a resource of information regarding elevators. A few websites are linked below:
  - The website http:science.howstuffworks.com/elevator1.htm describes the workings of a traction elevator and provides links to other resources
  - Jobsite safety in the elevator industry is discussed on http://safety.elevator-world.com/disaster.htm
  - The websites of the Elevator and Escalator Safety Foundation, http://eesf.org/, and major elevator suppliers such as The Otis Elevator Company and Schindler Elevators provide additional resources.
  - The National Elevator Industry, Inc. has other resources including a discussion of the performance based code for elevator safety (http://www.pbc-elevators.com/).

Mitigation Examples

Figure 6.4.10.2-6 Small "machine-roomless" traction elevator with flat belts at the Academy of Sciences, San Francisco, California (Photos courtesy of Eduardo Fierro, BFP Engineers). Clockwise: Overview of elevator at roof; view of guide rails and sheaves; top of cab showing belts; view down shaft at belts, counterweight, guide rails and guide rail brackets.

Mitigation Details



Notes: Provide lateral restraints for guiderails to resist design forces and accommodate anticipated interstory drift.
Elevators should be installed, maintained, inspected and repaired by qualified elevator technicians.
Inappropriate seismic restraints may compromise the safe operation of these systems.

Figure 6.4.10.2-7 Schematic view of geared traction elevator system (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.10 ELEVATORS AND ESCALATORS

6.4.10.3 ESCALATORS

Escalators typically span between two floors, and although most escalators run in a straight line, spiral escalators are found in some locations. The failure of any of the component parts of the escalator or escalator equipment could disable the functionality of the system.

TYPICAL CAUSES OF DAMAGE

- The primary components of an escalator system are the steps, chain, inner rail, chain guide, drive gear, handrail, handrail drive, electric motor, and electrical control panel. These components are often supported by a truss that spans between the floors. Any of these components could be damaged if not properly detailed or restrained; failure of any of the component parts could disable the system.
- Escalators, like stairs, may form a strut or brace between adjacent floors unless they are detailed so the system will accommodate inter-story drift. Damage could occur to the skirt, landing plate or other components not detailed to accommodate either an extension or shortening of the distance between the two landings.
- According to survey responses collected by the Division of Occupational Safety and Health Elevator, Tramway, and Ride unit, 65 escalators were damaged in the 1994 Northridge earthquake. It was reported that escalators came off upper supports, and several truss support angles had their bolts sheared off where one truss actually dropped. Glass came out of its supports and shattered, handrails collapsed. In addition, numerous deckboards, skirts and newels were damaged.

Damage Examples

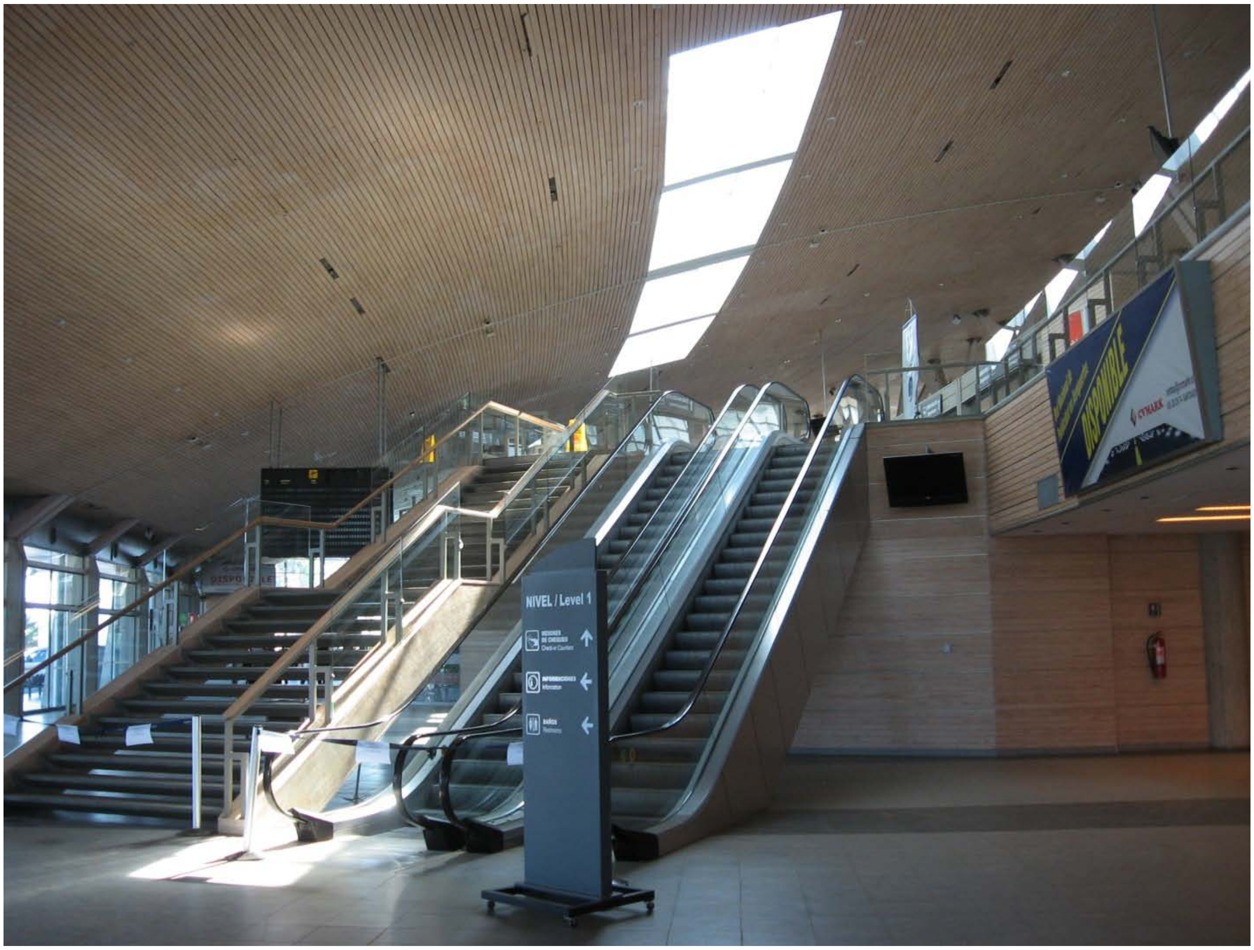


Figure 6.4.10.3-1 Extensive nonstructural damage resulted in the closure of Concepción airport in the 2010 magnitude-8.8 Chile Earthquake; both the stair and escalator were cordoned off to limit access to the upper level although there was no visible damage to the escalator (Photo courtesy of Rodrigo Retamales, Rubén Boroschek & Associates).

SEISMIC MITIGATION CONSIDERATIONS

- Each of the components of an escalator system need to be detailed to accommodate movement, or restrained and anchored to prevent damage in an earthquake. The system must be designed to accommodate the anticipated inter-story drift between the two connected floors. Where a truss is used to span between the two floors, the bearing seats should allow movement at one or both ends. Components such as the rail supports, handrails, landing plates, and skirts must be detailed to accommodate lateral deformations. All of the mechanical and electrical equipment needs to be properly anchored or restrained.
- Escalators have traditionally been designed to run continuously, whether they are in use or not. Some more energy efficient escalators operate on an intermittent basis and are triggered by the presence of passengers but otherwise are in a standby idle mode.
- All escalators should be inspected by qualified personnel following an earthquake. Unlike elevators, escalators typically function as a usable stair when they are not operating and could be used to facilitate evacuation following an earthquake.
- Elevator and escalator safety is governed by the prescriptive requirements in ASME A17.1, *Safety Code for Elevators and Escalators* (ASME, 2007a), a document that is continually evolving to reflect new elevator and escalator technologies. Local or state jurisdictions may have other elevator and escalator requirements.
- The internet provides information regarding escalators. Websites such as http://science.howstuffworks.com/transport/engines-equipment/escalator.htm describe the workings of escalators and provide links to other resources
- Some escalator models are offered with a seismic option; check for appropriate equipment before purchasing a new escalator.

Mitigation Details

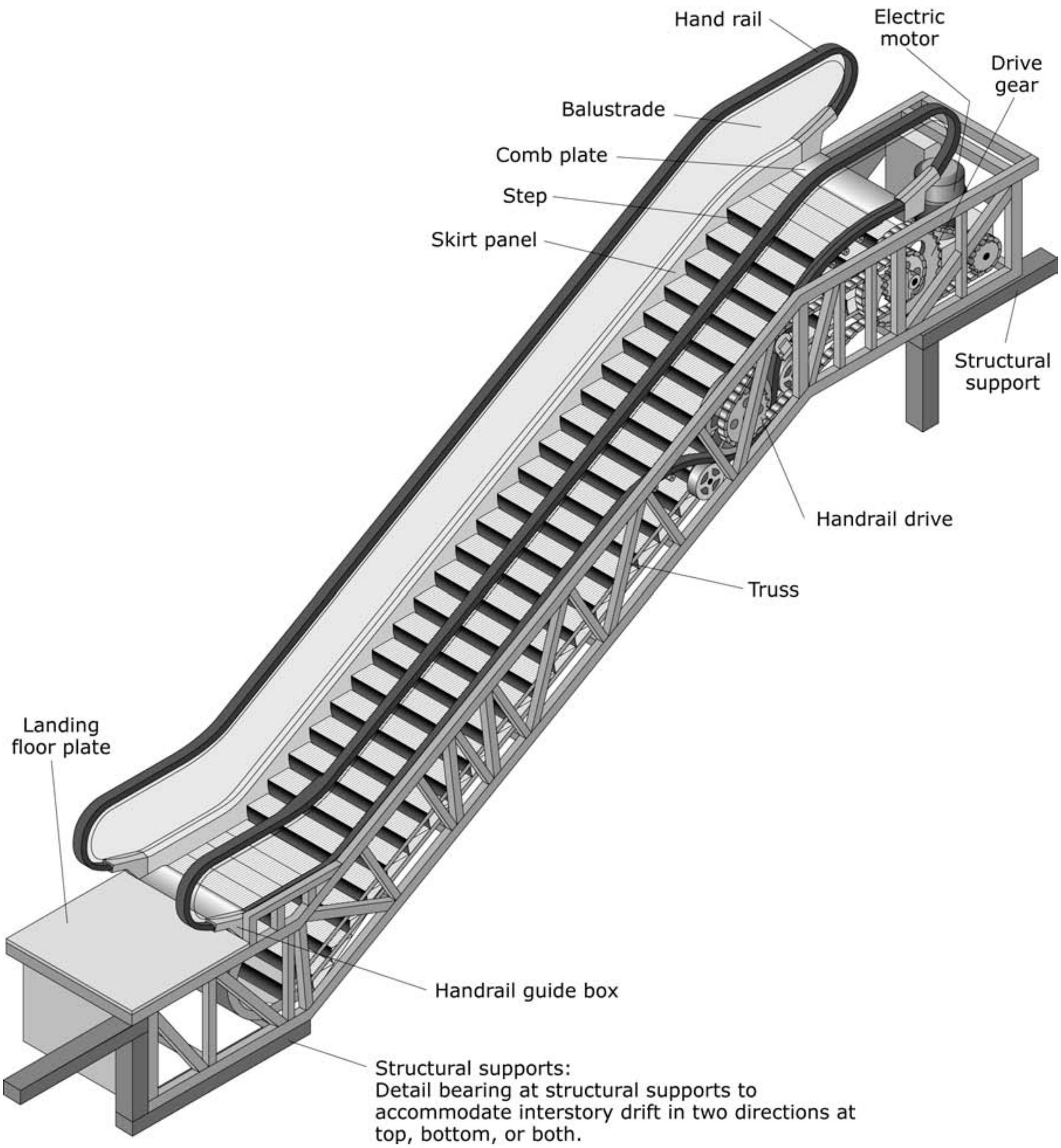


Figure 6.4.10.3-2 Schematic view of escalator (ER).

6.4 MECHANICAL, ELECTRICAL, AND PLUMBING COMPONENTS

6.4.11 CONVEYORS

6.4.11.1 CONVEYORS

Material handling conveyors come in all shapes and sizes from the conveyor belt at the grocery store checkout line, the clothing conveyor at the dry cleaner's, assembly line conveyors in clean rooms, airport baggage handling conveyors, to large industrial conveyors. They are used for many purposes, such as shipping, packaging, assembling, and manufacturing. The conveyors may be horizontal, inclined, hinged, straight, curved, spiral, screw, fixed or on wheels. Tall, inclined, or overhead systems may be a falling hazard; systems critical to facility operations may be important for post-earthquake functionality.

TYPICAL CAUSES OF DAMAGE

- Unanchored conveyors may slide and impact other items, tall or inclined conveyors may overturn, overhead conveyors or components may become dislodged and fall. Conveyors not designed for seismic forces may have damage to the component parts and connectors. Unrestrained conveyor motors and related equipment may be damaged and fall.
- Properly anchored conveyors may remain in place but the contents may fall. For tall or overhead conveyors, this could be a falling hazard resulting in injury and damage to materials or merchandise.
- The conveyor may shift and exceed the alignment tolerances and not be functional until repaired or realigned.

Damage Examples

Figure 6.4.11.1-1 Misalignment between rice storage hopper and conveyor following the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Rodrigo Retamales, Rubén Boroschek & Associates). Where various system components interface with a conveyor, the seismic restraints for the various parts should be coordinated to maintain alignment following an earthquake.

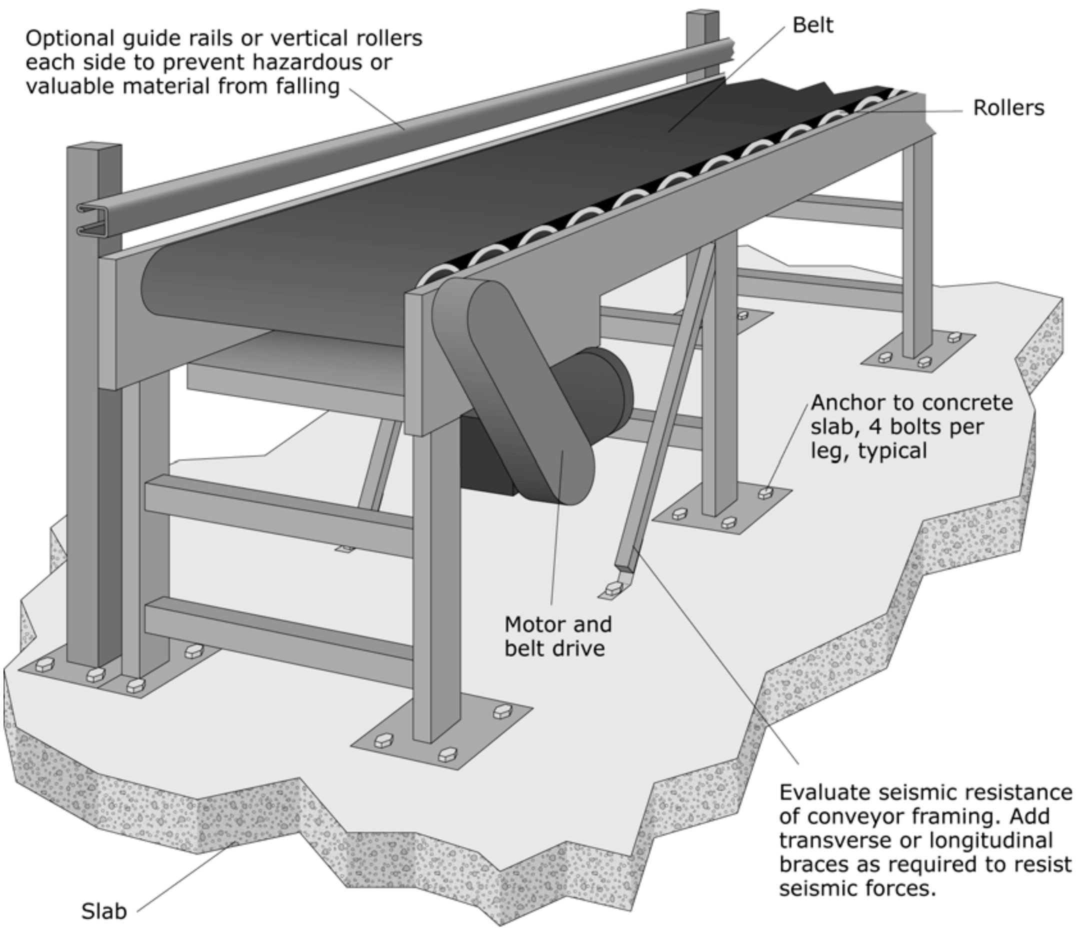
Figure 6.4.11.1-2 Damage to industrial conveyor used to feed grain silos in the 2010 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.4.11.1-3 Damage to industrial coal conveyor on jetty in southern Peru in the 2001 magnitude-8.4 Peru Earthquake (Photos courtesy of Eduardo Fierro, BFP Engineers). Conveyor was well anchored along entire length but detailing at the seismic joint between the jetty and platform did not allow sufficient movement, resulting in misalignment at end of conveyor and damage to the supports as shown at lower left. Approximately 10% of the rollers fell; these were held in place with friction fittings and did not have positive connections.

SEISMIC MITIGATION CONSIDERATIONS

- Conveyor systems and the associated motors, control systems, and control panels should be restrained or anchored to prevent earthquake damage. If life safety is the primary concern, tall or overhead components should be restrained to reduce falling hazards. If the conveyor is critical to continued operations, or the conveyed materials hazardous or particularly valuable, the system should be engineered to assure continued operations and the safety of the materials. In this case, the anchorage or restraints for interconnecting parts should be coordinated to maintain alignment tolerances following an earthquake.
- There are various conveyor mechanisms including belt driven, chain driven, gravity rollers, chain driven rollers, and flex link conveyors. Conveyors may be supplied with leveling feet which may not be sufficiently robust unless they have been designed for seismic loading. Floor to floor conveyors must be detailed the same as for stairs or escalators and be able to accommodate the anticipated inter-story drift. Where long conveyors are variously suspended, wall-mounted, or floor-mounted, the layout of the supports and restraints should consider the relative motion of the various attachment points. Special detailing is required where conveyors cross building separations or seismic joints.
- Some conveyors come supplied with predrilled base plates at each leg; these should be anchored to the floor slab. Existing conveyor platforms could be strengthened with transverse or longitudinal bracing if they have not been designed for seismic loading; clip angles could be used to anchor the legs to the floor. Check with the manufacturer prior to modifying existing equipment as equipment warranties may be affected.
- Where conveyed materials are hazardous or valuable, it may be prudent to devise guiderails or side restraints of some type to prevent the materials from falling off the conveyor in the event of an earthquake. Such restraints would have to be designed so that they do not to interfere with normal operations.

Mitigation Details



Note: Seismic restraints should not interfere with normal operations of the conveyor. Check with manufacturer before modifying with additional restraints.

Figure 6.4.11.1-4 Anchorage details for small material handling conveyor (ER).

6.5 FURNITURE, FIXTURES, EQUIPMENT AND CONTENTS

6.5.1 STORAGE RACKS

6.5.1.1 LIGHT DUTY SHELVING

This category includes light duty shelving units and sheet metal storage cabinets. These items are typically tall and narrow and may be heavily loaded.

TYPICAL CAUSES OF DAMAGE

- Shelving units may slide or overturn and the contents may become dislodged or fall. Where there are rows of freestanding or poorly anchored shelves, the failure of a few may result in progressive collapse of many. Broken bottles, spilled chemicals, mixed or damaged inventory are often the result of the failure of storage or display units.
- Mobile storage carts may roll, overturn, or impact other items. Stored contents may become dislodged or fall.
- Damage to contents or inventory that has fallen from shelving can be costly to repair or replace and may result in substantial business interruption.

Damage Examples

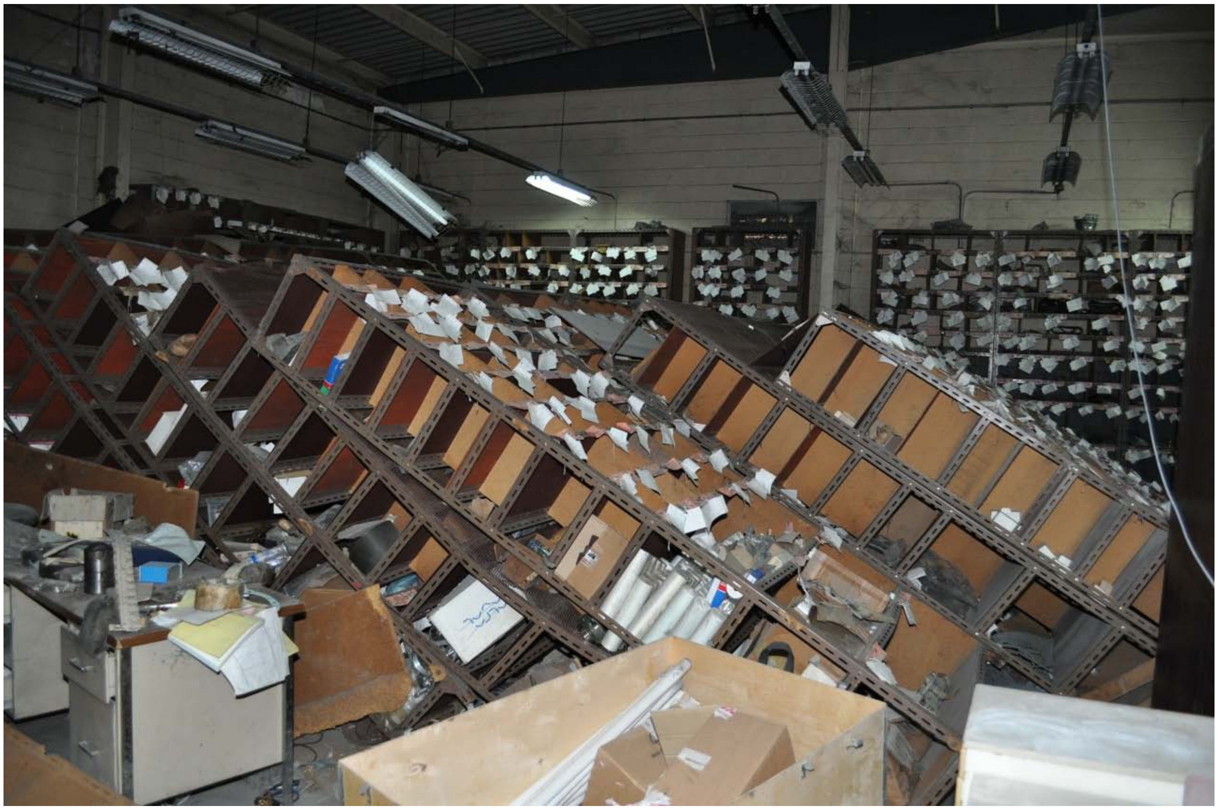


Figure 6.5.1.1-1 Collapse of row of unanchored freestanding shelving units containing spare parts at an electric power plant in Port-au-Prince in the 2010 magnitude-7 Haiti Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.5.1.1-2 Unanchored storage shelving slid nine inches without falling but contents scattered in the 2001 magnitude-8.4 Peru earthquake; unit lifted to original position prior to photo (Photo courtesy of Eduardo Fierro, BFP Engineers).

SEISMIC MITIGATION CONSIDERATIONS

- Permanent floor-supported shelving or storage cabinets over 6 ft tall must be designed as architectural components per ASCE 7-10, *Minimum Design Loads for Buildings* (ASCE, 2010). Bracing and anchorage for these units should be designed considering the weight of the unit and weight of shelved contents.
- For sheet metal cabinets or shelving, anchor units to floor, tie back-to-back units together, strap rows of units together across the top, or anchor units to an adjacent wall. Light duty steel storage racks may additionally require cross bracing.
- See Section 6.5.6.1 for recommendations regarding edge restraints and arrangement of shelf-mounted items. Do not locate cabinets or racks adjacent to doors or exits if their failure would block the exit.

- Any connections to stud walls must engage the structural studs. Stud walls and partitions may not have adequate lateral capacity to support many shelving units; engineering may be required. Where items are anchored to heavy partitions, the bracing or anchorage of these partitions to the structure above must also be checked for adequacy considering the seismic loads imposed by all anchored items.
- The details shown are intended for light duty units; heavy duty units with large loads may require engineering. See FEMA 460, *Seismic Considerations for Steel Storage Racks Located in Areas Accessible to the Public* (2005), for additional information on the performance of industrial storage racks. Some racks are available with enhanced seismic performance; check other resources, such as the internet for additional options.

Mitigation Examples

Figure 6.5.1.1-3 Mobile carts restrained at base with clip angles anchored to the floor and removable eyebolts attached from each cart to the angles (Photo courtesy of Maryann Phipps, Estructure).

Figure 6.5.1.1-4 Alternate restraint at base of mobile shelving unit (Photo courtesy of Maryann Phipps, Estructure).

Figure 6.5.1.1-5 Fixed base shelving units anchored with optional seismic base plate offered by manufacturer (Photo courtesy of Maryann Phipps, Estructure).

Figure 6.5.1.1-6 Mobile cart restrained at base with removable angles and eyebolts. Back-to-back units are interconnected (Photo courtesy of Maryann Phipps, Estructure).

Figure 6.5.1.1-7 Fixed base shelving units anchored directly to concrete slab through base plate (Photo courtesy of Maryann Phipps, Estructure).

Figure 6.5.1.1-8 Mobile shelving unit restrained by connection to strut fastened to full height metal studs (Photo courtesy of Maryann Phipps, Estructure).

Mitigation Details

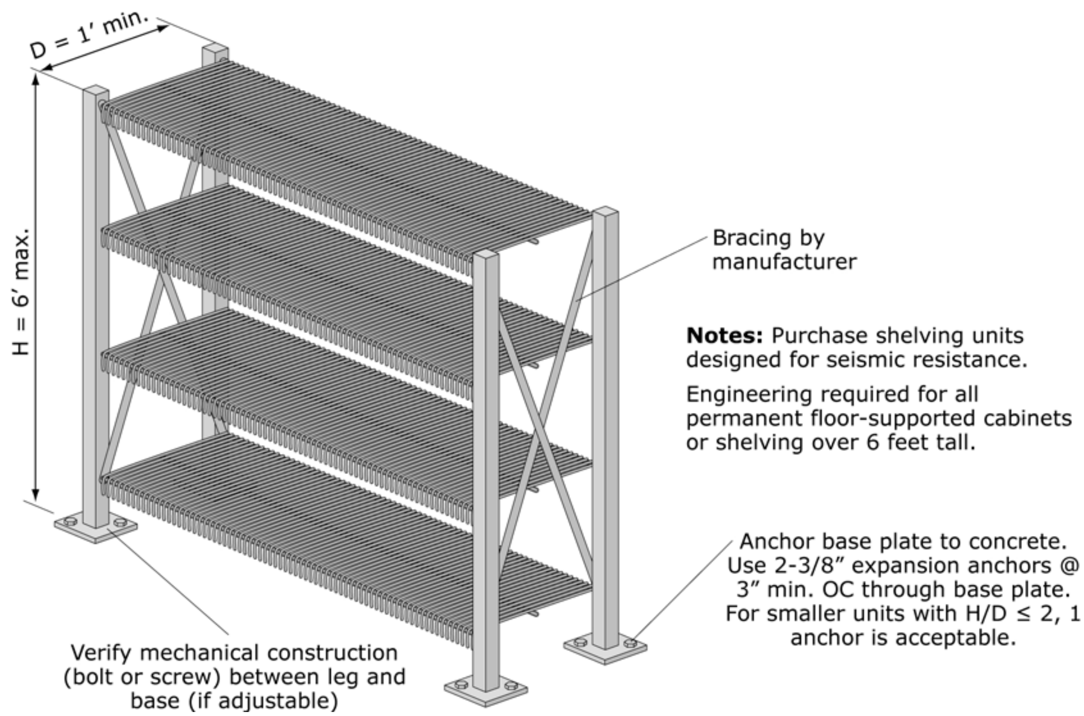


Figure 6.5.1.1-9 Light duty shelving (NE, ER).

6.5 FURNITURE, FIXTURES, EQUIPMENT AND CONTENTS

6.5.1 STORAGE RACKS

6.5.1.2 INDUSTRIAL STORAGE RACKS

This subcategory includes heavy duty steel pallet storage racks such as those found in public warehouse stores. These racks are typically 42 to 44 inches deep, 8 feet wide and up to 14 to 18 feet tall, often configured with two rows back-to-back. They are composed of specially designed steel elements that permit easy installation and reconfiguration consistent with merchandising needs.

TYPICAL CAUSES OF DAMAGE

- Industrial storage racks may slide or overturn, or failure of individual components can cause collapse or partial collapse.
- Stored contents may become dislodged and fall. Items falling from the upper shelves can cause serious bodily harm. Damage to merchandise or inventory may be costly to replace and reshelf and may result in significant business interruption.
- In cases with heavy stored products and light structural framing, collapsed racks and falling goods have caused damage to structural framing members and/or architectural cladding.

Damage Examples

Figure 6.5.1.2-1 Damage to overloaded racks during the 1994 magnitude-6.7 Northridge Earthquake (FEMA 460, 2005).

Figure 6.5.1.2-2 Spilled contents during the 1994 Northridge Earthquake (FEMA 460, 2005).

Figure 6.5.1.2-3 Rack collapse during the 1994 Northridge Earthquake. Note the minimal damage to shrink wrapped merchandise (FEMA 460, 2005).

Figure 6.5.1.2-4 Failure of anchored racks in the 2010 magnitude-8.8 Chile Earthquake. The racks are leaning precariously due to inadequate bracing in the longitudinal direction and weak connections between the components. The welded fitting at the end of the beam failed at the weld in many places. Note that most items were shrink wrapped so merchandise did not scatter (Photos courtesy of Rodrigo Retamales, Rubén Boroschek & Associates).

SEISMIC MITIGATION CONSIDERATIONS

- Project specific design of industrial storage racks is required. Each design must account for proprietary members and connectors that are used. Anchorage of the rack to the floor must be engineered and verification of the adequacy of the slab to accommodate forces generated by the rack is required. Storage racks may be classified as either nonstructural elements of nonbuilding structures, depending upon their size and support conditions. Check the applicable code to see which provisions apply.
- Pallet racks should be installed by trained and experienced personnel working from installation drawings provided by the rack designer. Reconfiguration from the as-designed condition should be evaluated by the designer.
- To prevent or minimize the falling hazard posed by stored overhead merchandise, a dual approach is recommended: prevent merchandise from falling down from one shelf to the next; and prevent pallets and individual merchandise from falling from the shelves into the aisles. The use of wire decking or spaced framing on each shelf will reduce the potential for fall-through of merchandise. Stretch-wrapping, shrink-wrapping, banding or use of integral pallet box units can reduce the potential falling hazard posed by pallets. Restraining bars, chains or cables, netting and/or slip-resistant containers can reduce the potential for loss of individual merchandise.
- FEMA 460 *Seismic Considerations for Steel Storage Racks Located in Areas Accessible to the Public* (2005) provides a comprehensive treatment of seismic resistant design considerations for steel storage racks.
- The Rack Manufacturers Institute (RMI) publishes industry-wide standards for engineering design of steel storage racks.
- Purchase storage racks designed for seismic resistance. Some industrial storage racks are now available with proprietary schemes for improved seismic performance such as base isolation, added damping, or shelves sloped toward the back of the rack.

Mitigation Examples

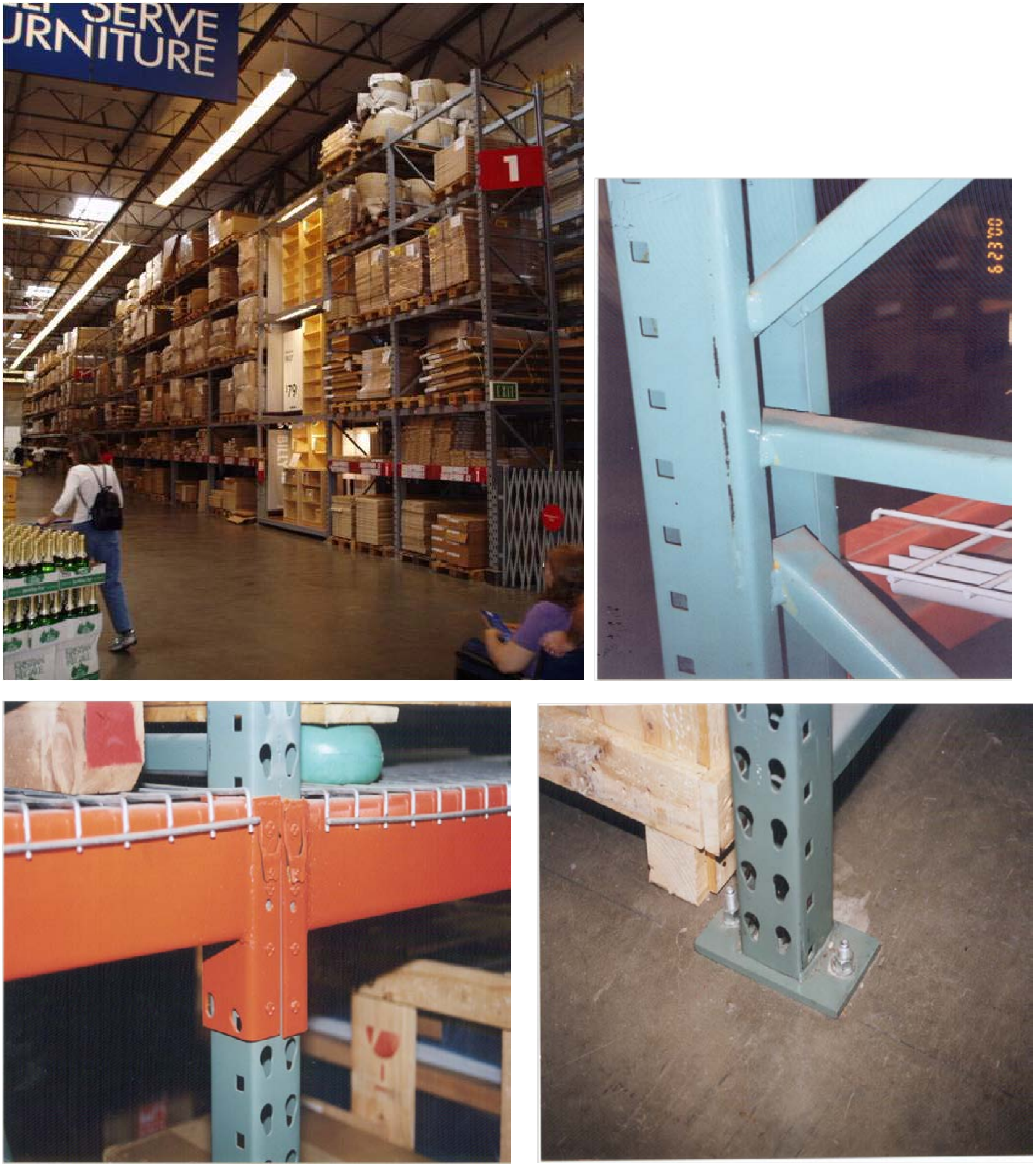
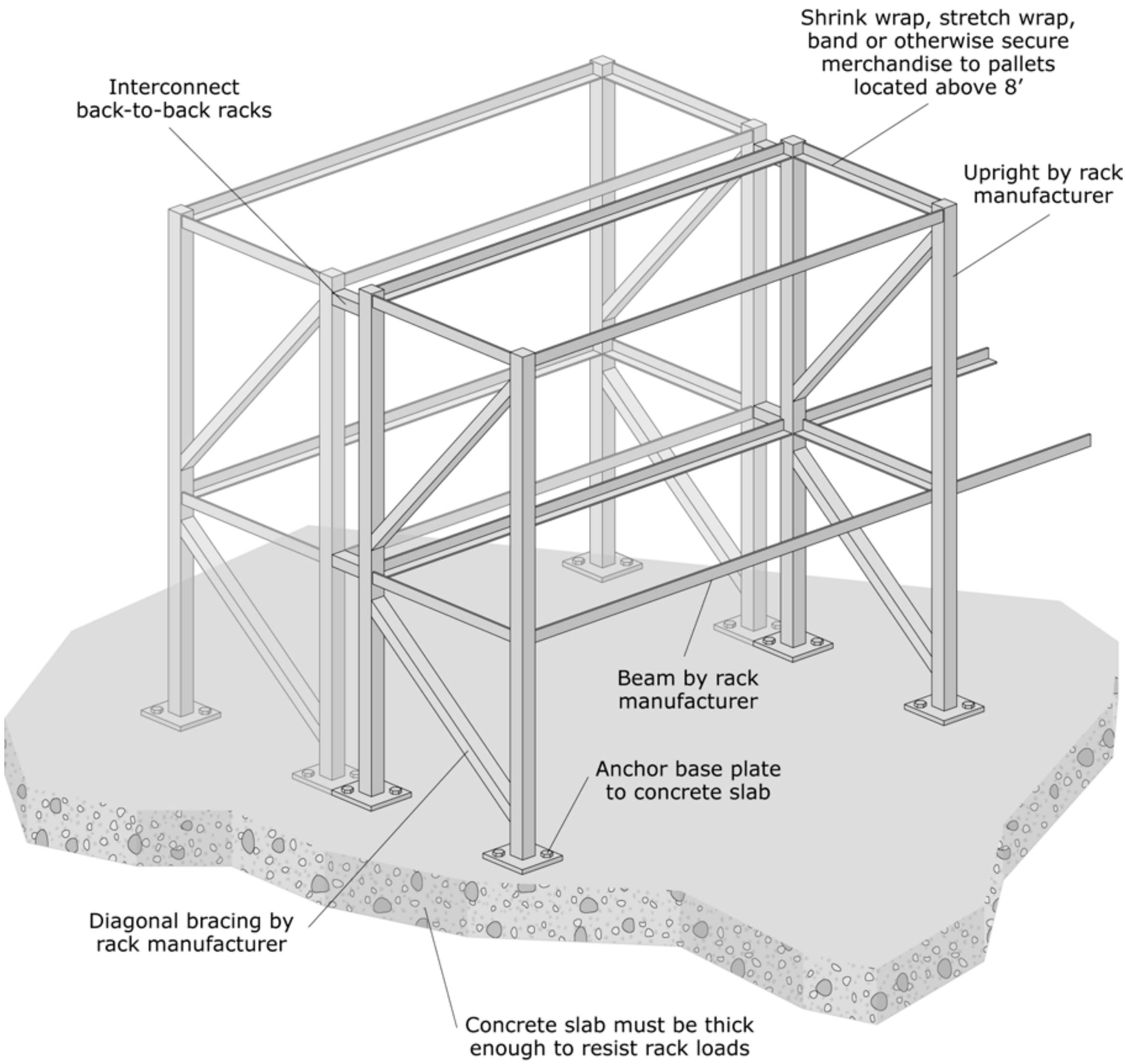


Figure 6.5.1.2-5 Typical pallet storage rack configuration and details (Photos courtesy of Maryann Phipps, Estructure).

Figure 6.5.1.2-6 Photo showing netting used to keep storage on upper portions of steel storage racks in a big box hardware store (Photo courtesy of Mike Mahoney, FEMA).

Mitigation Details



Note: Purchase storage racks designed for seismic resistance. Storage racks may be classified as either nonstructural elements or nonbuilding structures depending upon their size and support conditions. Check the applicable code to see which provisions apply.

Figure 6.5.1.2-7 Industrial storage rack (ER).